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CYBERNETIC MACHINES

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CYBERNETIC MACHINES

By

Yu. Bazilevskiy

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## CYBERNETIC MACHINES

Yu. Bazilevskiy

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During the building of the communist society, the enormous progress of science and technology with respect to increased industry and economy has been one of the objective laws of the development of the productive forces of the country. Scientific and technological achievements have not only made it possible to use material and power resources more completely and effectively, but have also laid the groundwork for the qualitative increases in productivity, the use of new materials, and technological methods.

Cybernetics, the science of effective control of processes and objects, is an important factor in the accelerated scientific-technical progress in all fields of knowledge and production.

The proposed program of the Communist Party of the Soviet Union provides for wide application of cybernetics, electronic computers, and control devices in production, scientific-research operations, structural engineering, systematic computation, and in the fields of accounting, statistics, and administration.

Electronic computers and control devices comprise the most important and the best developed class of cybernetic machines in widespread use. During the first decade of intensive scientific work, hundreds of attempts were made to create the most diverse types of electronic computers, and quite varied methods were used in the construction of circuits, memory devices, and structures. The expenditure of

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engineering labor in developing individual machines which were not used was  
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unjustifiably liberal. There were many such instances in our country.

The randomness in the selected technical solutions, logic, and command systems for the computers can be explained by the insufficient scientific background in seeking rational design solutions. The unjustified variety of technical solutions and external languages (command systems) has hindered production and, what is more important, the technical and mathematical use of the machines, and the training of the personnel.

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This disadvantage will be particularly intolerable when the field of the application of mathematic and control machines expands.

Already considerable experience has been gained in scientific and design operations, in the production and use of electronic computers, and a number of important investigations have been conducted in the fields of logics and the theoretical bases of cybernetics. Now is the time to re-evaluate the methods and practices of the engineering of such devices, and introduce them into the vitally important fields of human activity.

### The Logic of Cybernetic Machines

The basic problems of cybernetics are solved on machines which simulate the mathematical structure of the process and the control methods. Periodic mass reproduction of the algorithm in the machine makes it possible to process the streams of input information and produce the resultant (output), used for purposes of studying, projecting, or controlling the process.

Cybernetic machines include: logical automatic machines and discrete operation circuits; devices and systems for the accumulation, distribution, and conversion of information structure (code); computers, analyzers, and discrete-operation machines; and devices and systems (discrete or continuous action) whose logical structure or functioning reflects the given process or control algorithm.

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Electronic computers with program control have been widely developed and put  
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into operation. Let us briefly trace the basic development of the logic of these  
machines, and the associated scientific problems.

Machines with program control comprise a separate class of logical automatic  
machines as a result of the improvements in the individual circuits and devices  
designed to fulfill individual forms of the mathematical functions. This develop-  
ment has come about as follows: by considerably increasing the number of elements  
and the number of possible internal states of the circuit; by isolating the memory  
elements and arranging them using address systems; by complicating the functions and  
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generalizing the logic and arithmetic operations; by separating the circuits which  
control the input and output of information and revert to the memory cells and  
operational regimes; by formulating a special language for the machine (command  
system) and introducing into it control information (program in the language of the  
machine) for each problem; by means of automatic adaptability of the machine for  
processing the control information (program) when solving the problem and reducing  
this information to a new processing cycle; by using control programs of the various  
logical levels; by introducing the problem in conventional reduced form, and formula-  
ting the operational program in the machine itself.

Computers with program control have become a universal medium for realizing the  
algorithms of the most diverse problems and objects.

The unusual flexibility of programming, reprogramming, and program conversion  
in the machine, and the possibilities of further essential improvement in the logic  
cause the general purpose digital computers with program control to be stable pro-  
spective cybernetic devices, designed for broad, regular, introduction into all  
branches of science, technology, and the economy.

The experiments and the first results of using general purpose digital com-  
puters<sup>2</sup> for solving scientific problems in systematization, delivery, and transpor-  
tation, have shown that the information capability and the output of these machines<sup>1</sup>

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should increase considerably.

Increasing the memory capacity to tens of millions of digits, in conjunction with the requirement of minimum record, search, and access times will require the construction of a multi-stage memory system with specialized information exchange methods.

One of the important theoretical problems is to create a multi-stage memory system with a logic for the interaction of streams of information between its units which would assure minimum expenditure of time with sufficiently full utilization of the entire capacity of the memory system.

Study should be made of the possibilities for program and circuit change of the memory access regimes relative to the specifics of the various problems to be solved.

It is possible to introduce an internal language, microcontrol, and recursive regimes for control of the memory units. In this case, individual circuits are developed for the streams of information for specific problems.

Study of the possibility of automatic classification of input information, and "coloring" its various forms with attributes has created grounds for designing associative memory systems which are distinguished by rational spacing of the information and a considerable decrease in its access time. In such systems, the recording and access of information is accomplished not by means of fixed memory cell addresses, but due to the operatively variable attributes of the information groups.

The requirement of sharply increasing the machine output has stemmed from the general tendency toward increasing the amount of calculations when solving large-scale problems.

The mathematical aspect of this problem includes the treatment of problems dealing with the logical structure of the machine, with the numerical solution methods, and with optimum programming. Let us cite several of the research

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directions leading to this goal: seeking and studying new systems for calculating and rationally coding the digits, making it possible to devise time-saving circuits for calculation operations (e.g., a system for calculation in residual classes, etc.); construction and study of the logics of multi-register arithmetic and elementary function generators; the packaging of information and the accelerated conversions of words (digits) with variable length; the use of reduced tables of special functions; the setting up of an optimal program for solving a problem, making best use of the machine equipment and performing various operations simultaneously (in parallel).

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One of the most important theoretical aspects for increasing the machine output is to increase the structural reliability and to cut down the time lost to functional control and diagnosis of defects. The design of interference-free and reliable circuits using not-too-reliable elements; the use of majority and self-correcting logic systems for converting and storing information; the design of circuits which can be subjected to rapid functional control and localization of the defective portion; are all problems which should attract the continued attention of researchers and designers.

The problems of structural reliability include: development of algorithms, numerical methods, and programs which are interference-proof against individual errors (disturbances, breakdowns in the machine apparatus). Example of interference-proofing methods are: iteration methods, probability methods (Monte-Carlo), and programs with special cycles for direct or indirect control of the calculation results.

As the amount of information and the number of operations necessary to solve a cycle of problems have increased, computational control has become more complex, the working programs have become logically complicated, and many thousands of commands have been reckoned. Under these conditions, there must be further improvement in the control logic of the machines, and automatic development of optimal fragmentary subroutines.

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The development of index-registers and index-arithmetic, as well as the method of multistage construction of subroutines, has led to the method of control words formed in the machine on the basis of analysis of the properties of the input information, the characteristics of the intermediate computation results, and the parameters of the initial algorithm. The control word becomes a temporal logic function of the current states of the program, the input information, and the intermediate information. Corresponding reprogramming of the logic of the control devices for working with control-words makes it possible to obtain the structure of machines which are quite capable of versatile processing of complex combined flow of information.

The second of the above-mentioned possibilities consists in the operational automatic formation, at various stages of algorithm satisfaction by the machine, of commutations in the circuits of its units (e.g., according to the principles of microcontrol) which will permit accomplishment of effective special operations characteristic (often encountered) in this part of the problem.

Persistent theoretical study along these lines will aid in the creation of new types of general purpose digital computers with extremely high output, millions of operations per second.

Another important theoretical problem, used as the basis for the creation of new promising types of cybernetic control machines, is the automatic discernment of the structural properties of the information, and formation of concepts and opinions in the machines.

In recent years, these problems have been worked on in many research centers. The most pressing problems are discernment, automatic perception, and correction of noise-distorted speech, printed text, radar and other information. The formation of concepts and opinions in machines is closely associated with the processes of adaptation to the medium, and the instruction of cybernetic machines. In this regard, it is extremely important to investigate the logical structure of biological

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phenomena and simulate them. We know of an experiment in the simulation of a complex system of plastic neurons using general purpose digital computers. These computers also make it possible to conduct a vast program in the simulation of perceptions: systems for the statistical analysis and discernment of the structural properties of information.

The creation of optimal instructable cybernetic machines is assured by the large-scale logic and mathematical investigations being carried out. There must be systematic development of the theoretical problems in the general theory of automatic machines, logical nets, temporal logical functions, and the theory of programming.

A serious increase in the level of theoretical works is an essential condition for the accelerated development and operation of cybernetic machines.

#### Assuring the Leading Development of Technology

Cybernetic machines are based on modern computer technology. The specific technical problems for the next and subsequent stages in the development of control systems are to increase the speed and reliability of the components of the cybernetic machines, and to reduce the size and the cost.

As is known, logical circuits can consist of the most diverse physical systems and elements: lever mechanisms; pneumatic devices; electromechanical relays; vacuum-tube, thyatron, and semiconductor electronic circuits; light-optical converters, and many other elements.

Present computer technology combines three generations of machines, with rather varied technical backgrounds. The first generation consists of electronic machines whose basic element is the vacuum tube. This includes the majority of the several thousand machines of the past decade which are presently in use in various countries. The second generation consists of machines using semiconductor circuits. These are more compact and economical devices which are gradually replacing the

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~~tube-type machines.~~ The third generation consists of the machines of the future, using microminiature elements and utilizing the technology of the physics of thin films and new physical principles. Intense study along these lines is being done in many countries.

Experiments in the development of electronic computers with complex logic and a great amount of apparatus have led to the generally-accepted principle of constructing various structures of standard unified microcomponents (elements, modules) which perform elementary logical and memory functions. For mass-produced computers and control machines for various purposes, all the technical and functional components should be unified and continually produced.

Particular attention should be devoted to the problem of the technical reliability of computers and control machines. For these types of devices the problem of reliability is increased for two reasons: the applied discrete logic makes them very sensitive to distortion of information and particularly, control signals; errors in individual signals often result in great distortion of the entire trend of the solution to the problem, and to the formation in incorrect output information. On the other hand, the great many elements which compose the complex system make it very difficult to check and correct the action of the machine.

Scientific, design, and technological organizations and factories must carry out a great many operations and investigations to assure high technical reliability of electronic computers and control machines.

Machines of the third generation comprise the main direction in the development of the technology of computers and control machines. At present, various countries have under development more than ten various technical types of microminiaturization of machine elements and components. Let us mention several of them: high-density mounting (macromodules, welded mountings); the method of micromodules (the RCA micromodules, microelectronic point mounting, ceramic-base microcircuits); integral circuits (solid-state circuits, molecular electronics); cryogenic circuits (cryotrons).

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~~First~~ American experts from specialized companies give the following predictions as to the development of microminiature radio-electronic apparatus production: By 1965, more than ten times as much will be spent on microminiaturized radio-electronic apparatus than was spent last year; by 1980 more than 85% of all radio apparatuses produced will be microminiaturized. It has been found, from a comparison of various factors, that the module methods of producing radio-electronic apparatuses are but a temporary solution to the problem of micro-miniaturization.

By 1970, the predominant method will be that of thin films, and by 1970-1975 it will be replaced by molelectronics and solid-state circuits. Cryogenics is particularly important in the fields of computers and cybernetic machines.

The particular importance of the microminiaturization of cybernetic machines stems from the following two concepts.

First, the concentration of logical circuits in small volumes creates radically new conditions for the construction of highly complex cybernetic machines, approximating the human brain in information ability and adaptability. Second, the method of microminiaturization (in particular, molelectronics and solid-state circuits) give the principle solution to the problem of reliability in cybernetic machines.

The complex development of scientific-technical problems and the design of a family of computers and control machines of the third generation, and also their mass-production, is an important national economic problem. It should be provided for in the projected state plan.

#### Machines Created by Machines

Cybernetic machines are self-adaptable, i.e., they can be used with great success to rapidly and effectively create new similar models.

The famous mathematician J. von Neumann proposed the structure for automatically reproducing logical automatic machines, i.e., machines which would produce copies of themselves. Let us examine the process of the creation of a new model of a

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computer or control machine.

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The initial material for its design is the results of analysis of a group of typical problems to be solved. Comparative analysis of the possible numerical methods of the solutions, experimental programming, and "plying" on general purpose digital computers makes it possible to obtain statistical evaluations for the parameters which characterize the number of calculations requiring operative, periodic, and long-term memory, time delays for the problem-solution cycle, and the density of the standard logical and arithmetic operations. These data are the basis for preliminary

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selection of the structure and operational principles of the new machine.

The second stage, refining the macrostructure and command systems of the projected machine, which is presently done by humans solely on the basis of design experience, can also be automated by simulating several of the structural variants of the new machine on general purpose digital computers.

The third stage in developing machine logic consists in compiling a functional circuit (microstructure) from the given elementary circuits (cells, modules), and verifying the validity of the obtained complex system containing thousands and tens of thousands of elements.

Simultaneously with the future development of the theory of logical functions, nets, and methods for minimizing them, there must be development of methods and introduction of program minimization with use for digital computer calculations.

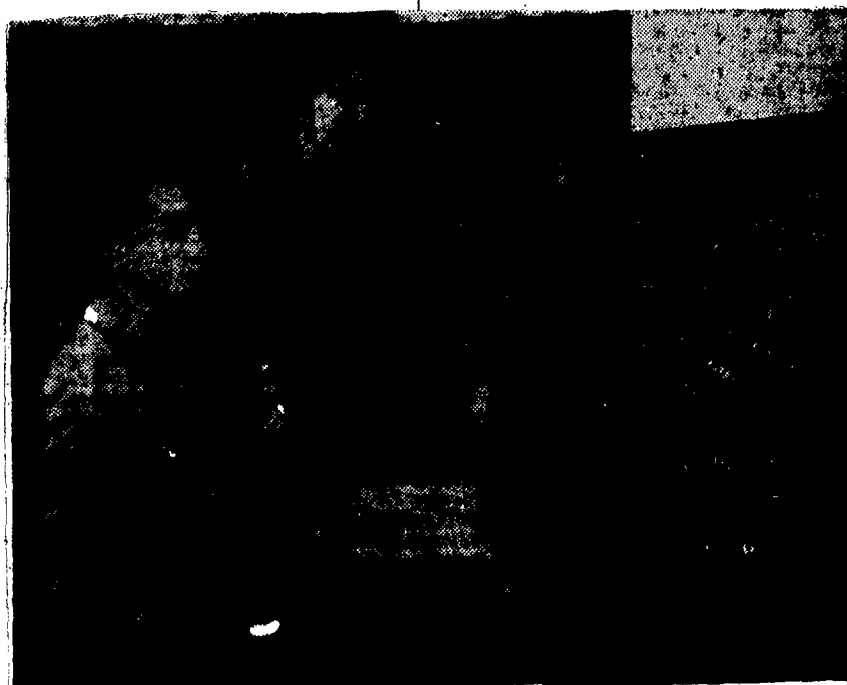
Let us turn our attention to the need for accelerating careful tests of the machine elements and components. The quite complex logical functions and the abundance of various static and dynamic regimes for checking each assembly make it extremely complex and difficult to carry out functional verification and find defects.

There is need for a basic re-examination of the methods for creating computers and control machines, increasing the engineering development methods to a new qualitative level, and setting up this branch of technology on a present-day scientific

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Computer Center of the Academy of Sciences of the USSR. Here, high-speed electronic computers are solving complex equations. They are performing operations required by scientists in the most diverse branches of science. In the photograph: Senior Computer Engineer Z. Vadova and Junior Research Worker E. Chistova operate a computer.

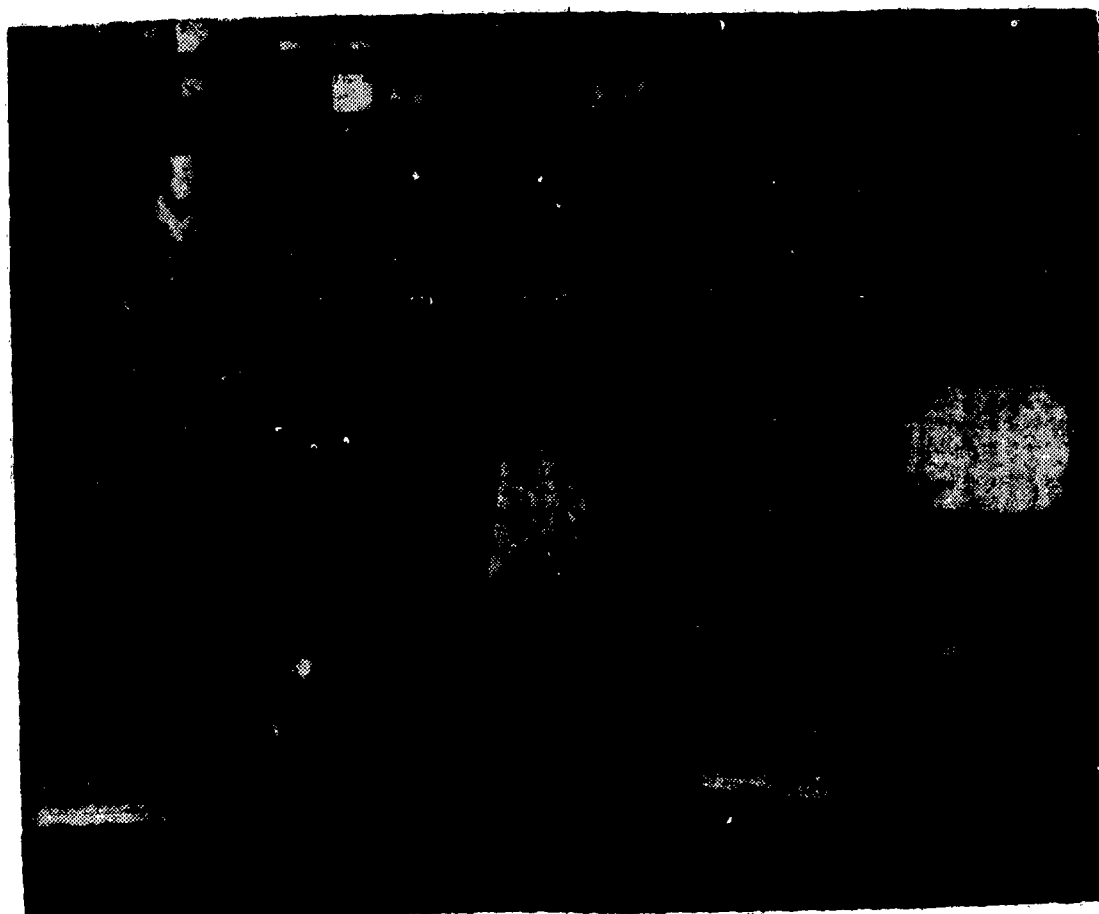
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All units of the Kremenchug Hydroelectric Station are ready two years ahead of time. In the photograph: Main control board of the hydroelectric station. At the left - shift supervisor, Engineer V. P. Yemel'yanova.



foundation. ~~TEXA~~ direct result of such measures in the near future should be the sharp curtailment of the time required to create new models of machines, and an essential improvement in their technical-economic and operational characteristics.

As a result of the accomplishment of a prospective plan for the development of electronic computer technology and cybernetics, there will be a great increase in the efficiency of the control of the national economy, and an increase in the productive forces.

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